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(71) Applicant(s)
Hohner Automation Limited
(Incorporated in the United Kingdom)
Whitegate Industrial Estate, WREXHAM, LL13 8UG, United Kingdom

(72) Inventor(s)
Walter Bloechle

(74) Agent and/or Address for Service
Alistair Hamilton
Ty Eurgain, Cefn Eurgain Lane, Rhosesmor, MOLD, Flintshire, CH7 6PG, United Kingdom

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(56) Documents Cited
WO 96/27118 A1 US 5177393 A US 4977316 A
US 4902885 A

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(54) Abstract Title

Optical encoder with variable phase sinusoidal output

(57) An optical encoder for sensing modulated light has a rotating disc (5) or rectangular plate. The disc (5) has at least one circumferential track by which light is modulated so as to produce a sinusoidally varying light transmission coefficient as the disc is rotated. The transmission coefficient is modulated through several sinusoidal cycles per revolution of the disc or length of the plate. In some embodiments, the disc has additional tracks with light and dark sections to implement an absolute position encoder. A constant light source (4) illuminates the disc and light sensors (6-69) detect light passing through it. The light detectors (6-69) may be disposed in an array substantially equal to the period of the sinusoidal pattern, the sensors being monitored in a scanning pattern.

Fig 2

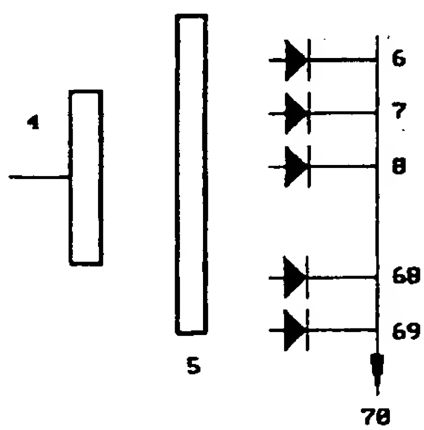

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Fig 1a

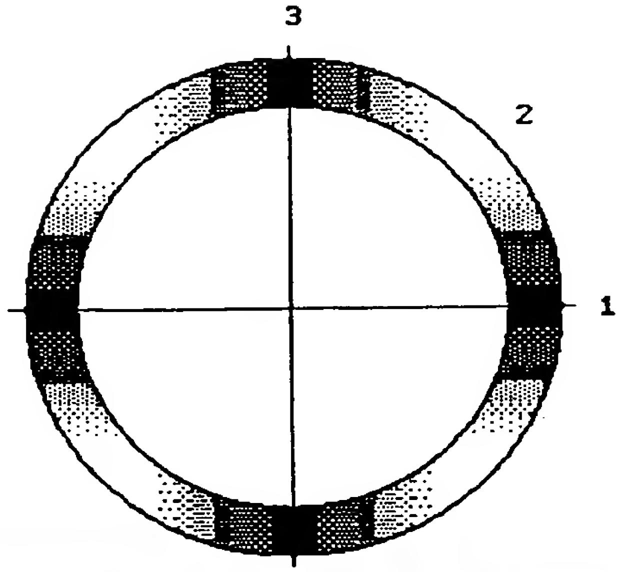


Fig. 1b

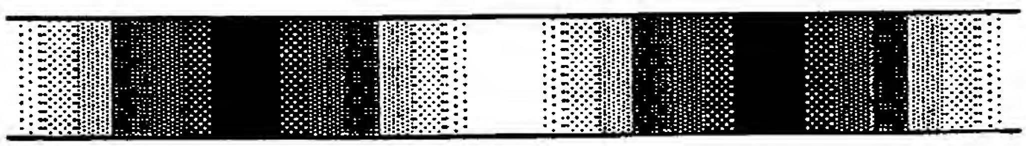


Fig 2

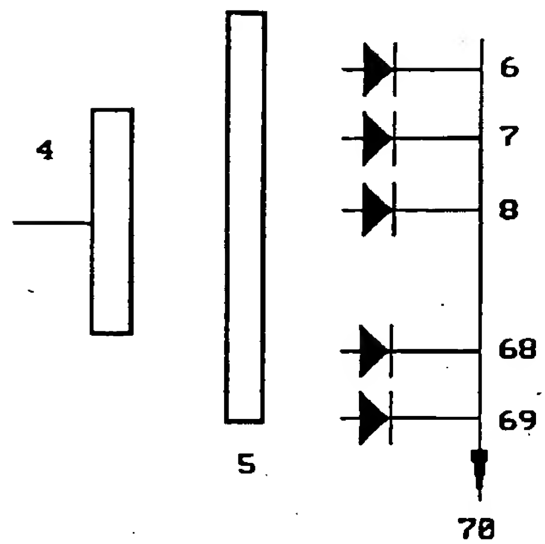


Fig 3 A

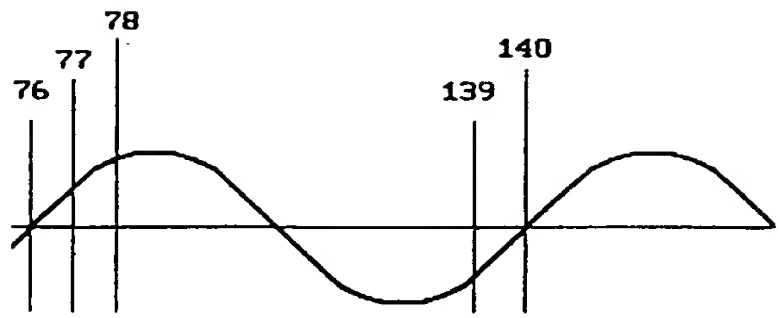
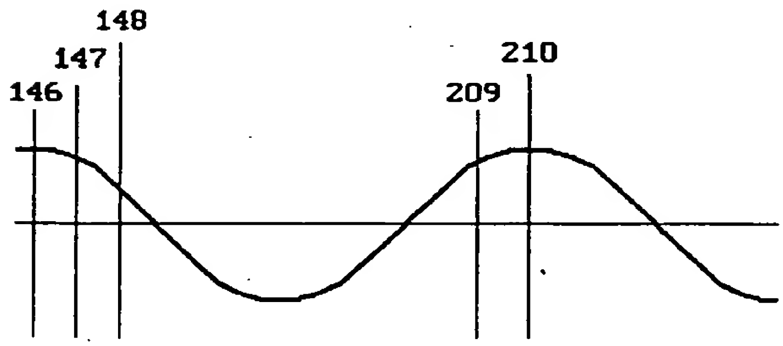


Fig 3 B



Optical Encoder with Variable-Phase Sinusoidal Output

BACKGROUND OF THE INVENTION

Field of the Invention

An optical system senses light transmitted through a repetitive pattern of light and dark spots on a circular disk or a rectangular plate, and converts it into a continuous stream of sinusoidal analog data. The analog output signal is phase-shifted relative to a trigger signal in such a way as to give precise information on the angular orientation or linear position of the disk. The output is compatible with that produced by a resolver or an LPDT (Linear Phase Differential Transducer).

Description of the Prior Art

Incremental and absolute encoders are used to determine the position or velocity of a rotating shaft or linearly moving core. In their simplest form such encoders typically produce high-frequency analog outputs in the form of two square waves which are 90 degrees phase-shifted relative to each other. The square waves are generated by dark and light areas on an optical disk in the case of a shaft encoder. The angular resolution of the device is limited by the number of dark lines engraved on the disk. In order to achieve high-precision measurement of position it has therefore been necessary to encode the disks in an optically precise way with a large number of lines. Other devices have attempted to improve resolution beyond that implied by the number of lines encoded on the disk, by developing interpolation schemes to infer information for those positions in between successive dark lines. One method has been to use multiple sources of pulsed light, and multiple detectors, where each source is phase-shifted in time relative to its' neighbor. This requires precise alignment of multiple devices and does not produce a smooth interpolation signal between successive dark lines. Another approach has been to modulate

the intensity of the dark lines in a smooth way so as to produce a sinusoidal output instead of a square wave. This has led to the "sine-cosine" encoder, with two output signals whose relative amplitude can be used to infer angular position very accurately. This approach, however, requires very precise positioning of two detectors relative to each other, and requires high-speed digital data-acquisition techniques. Additionally, it is susceptible to transient electrical noise since the signals are sampled instantaneously to determine position, rather than being sampled for a full sine-wave cycle.

SUMMARY OF THE INVENTION

The general purpose of the invention is to produce a sinusoidal output wave whose phase shift will be proportional to the angular shaft position. A single rotation of the shaft produces a large number of cycles of the sine wave. The amplitude and frequency of the sine-wave output are both constant, and the sine-wave output continues at the same amplitude and frequency even when the shaft angle is stationary. A single source of light is used to illuminate a large number of closely spaced detectors, and the light intensity is constant in time. The light passes through an optical disk with a pattern of alternately light and dark radial lines on it, arranged in a circumferential array, which modulate the transmitted light to produce a sinusoidal pattern of illumination of an array of detectors. The array of closely-spaced detectors is scanned serially at high speed to produce a continuous stream of analog output data which emulates the output produced by a resolver or LPDT (see Ref. 1).

A distinguishing characteristic of the device is that it is not necessary, or even desirable, to digitally sample the output signal as is done in Ref. 2. Instead, the output signal is processed in its' original analog form by an ASIC (Application Specific Integrated Circuit) which is generic in nature, and not specifically designed for optical encoders. A second distinguishing characteristic of the device is that a single optical source of illumination can be used at constant intensity, which greatly simplifies the optical

characteristics of the device, while other devices of this type typically require pulsing and/or time phase-shifting of multiple optical sources relative to each other (see Ref. 3).

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A shows an encoder disk with a pattern of dark lines drawn on it, so as to modulate the transmission of light through the disk. The pattern shown from **1** to **3** repeats itself around the entire disk.

Figure 1B shows an encoder rectangular array with a pattern of dark lines drawn on it, so as to modulate the transmission of light through the disk. The pattern shown from **1** to **3** repeats itself linearly for a number of cycles.

Figure 2 shows a side view of the light emitter **4**, code disk **5**, and 64 closely spaced light detectors **6-69** leading to an analog output signal at **70**.

Figure 3A shows a typical output signal at location **70**, plotted as a function of time, for a case where the encoder is at a fixed position T1. Also shown are the times **76-140** when specific optical detectors **6-69** are sampled to determine light intensity.

Figure 3B shows a typical output signal at location **70**, plotted as a function of time, for a case where the encoder is at a different fixed position T2. Also shown are the times **146-210** when the same set of optical detectors **6-69** are sampled to determine light intensity.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In a preferred embodiment of this invention, multiple transmissive sections **1-3** of an optical disk are patterned non-uniformly such that, if the code disk were rotated and a stationary detector were used to detect the light transmitted through the disk, then the

output signal as a function of time would be as in Fig 3A or 3B, apart from an arbitrary phase shift in time. In a typical embodiment the disk diameter would be 3.2 inches, having around its' circumference 32 sections of the type shown from **1** to **3** in Fig. 1, such that a single full rotation of the disk would generate 32 full cycles of the sine wave shown in Fig. 3. In a typical embodiment the distance from **1** to **3** in Fig. 1 would be 8 mm. Similarly the distance between the photodetector at **6** and the photodetector at **69** would also be 8 mm., there being 64 separate photodetectors within this range, each separated from each other by 125 microns, such that a serial scan of the light intensity at locations **6** to **69** in Fig. 2 would generate a sine wave of the type shown in Fig. 3A from locations **76 - 140** even if the code disk were stationary. In this embodiment the detectors are scanned serially in a cyclical fashion, and the output signal at location **70** at any instant of time represents the light intensity at a specific site between **6** and **69**. In a typical embodiment the scanning rate for sampling the detectors serially would be 512 kHz such that each individual detector is sampled 8000 times per second. For a stationary code wheel the output signal is then of the form shown in Fig. 3 with a typical frequency of 8 kHz. The nature of the device is such that a change in angular position of the code wheel will induce a phase shift in the output signal from that shown in Fig. 3A to that shown in Fig. 3B, without changing the amplitude of the signal, where amplitude is defined as the rms. value of the signal. The phase shift is such that at one angular position of the optical disk the signal sampled at location **6** will be represented by point **76** in Fig. 3A, while at another angular position the signal at location **6** will be given by point **146** in Fig. 3B.

A further feature of the device is the presence of a reference signal of frequency 8 kHz which is synchronized with the time at which a specific detector such as detector **6** in Fig. 2 is sampled. One thus has two signals of the same frequency with a phase shift between them which is proportional to the angular position of the disk. This pair of signals is an exact emulation of the typical output produced by an LPDT, and is processed electronically in a manner identical to that of an LPDT using a suitable ASIC. The characteristic features of the ASIC used in this invention are that the two signals are compared electronically to determine the phase difference between them without at any

time attempting to digitize the two signals. Only after the phase shift has been determined is it possible or necessary to digitize the phase shift information for purposes of electronic communication with other devices. This relieves the ASIC of the onerous task of attempting to digitize a signal at very high speed and greatly simplifies the electronics of the device. It also provides for a great deal of automatic noise rejection, since the entire waveform shown in Fig. 3 is being used to determine the phase shift, the waveform lasting for a period of about 125 microseconds, while any attempt to digitize the signal to obtain phase shift information would have to sample the signal much faster with a typical time period of 2 microseconds in the case of a 512 kHz. scanning rate.

The device described here can be reasonably considered to be an "infinite resolution" encoder in the sense that the precision is limited only by the quality of the optical patterns engraved on the disk and by the electronic precision of the circuit which determines the phase shift, and is not limited by the number of optical detectors used to measure the light intensity.

It will be appreciated that although only a few exemplary embodiments of a variable-phase sinusoidal output optical encoder have been described and illustrated, numerous variations and modifications will be apparent to those skilled in the art. For example, the optical pattern can be either circular or rectangular, and the detected motion can be either circular or linear. Similarly, the physical dimensions of the photodetector array and the scanning frequency and number of detectors can be altered without in any way affecting the nature of the invention. Therefore it should be understood that, within the scope of the appended claims, the invention may be practised otherwise than as specifically described.

REFERENCES

1. Linear differential transformer with constant amplitude and variable phase output.
   US patent : 4,437,019 Inventor : Jacob Chass

2. Signal processing apparatus for pulse encoder with A/D conversion and clocking.
   US patent : 4,972,080 Inventor : Mitsuyuki Taniguchi

3. Angular position detector
   US patent : 4,710,889 Inventor : Thomas Wason

CLAIMS

1. An optical encoder for sensing modulated light transmitted through a rotating disk, the disk containing at least one circumferential track in which the light is modulated so as to produce a sinusoidally varying light transmission coefficient as the disk is rotated, with several cycles of the sinusoidal wave per each revolution of the disk. The disk may or may not contain additional tracks encoded with light and dark sections such as would be appropriate for either an incremental or absolute position encoder.

2. An optical encoder for sensing modulated light transmitted through a moving rectangular plate, the plate containing at least one track in which the light is modulated so as to produce a sinusoidally varying light transmission coefficient as the plate is moved linearly, with several cycles of the sinusoidal wave per length of the plate. The plate may or may not contain additional tracks encoded with light and dark sections such as would be appropriate for either an incremental or absolute position encoder.

3. A light transmission device capable of providing an equal amount of illumination upon an area of the disk or plate corresponding to a full cycle of the sinusoidal pattern imposed on the disk or plate, wherein the light intensity of the source is constant in time.

4. A light detection device consisting of a single monolithic array of several light sensors closely spaced together such that the physical length of the array is equal to the physical period of the sinusoidal pattern imposed on the optical disk or plate.

5. A serial scanning procedure wherein each of the individual light sensors in the array is monitored to measure the intensity of the light illuminating it. The scanning procedure to be such that all of the individual sensors in the array are scanned sequentially at high speed, with the scanning to be restarted automatically at the start of the array, so

as to produce a continuous stream of electrical signals proportional to light intensity at different locations in the array.

6. A reference signal of the same frequency as the frequency with which the light sensor array is being scanned, being synchronized with the time at which the first sensor in the array is being measured.

7. An electronic analog signal processing system which measures the phase shift between the above two signals and yields an output signal proportional to the phase shift, the signals to be processed by this system being an exact emulation of the typical output produced by a Linear Phase Differential Transducer.

The Patent Office

INVESTOR IN PEOPLE

Application No: GB 9902030.7   9   **Examiner:** Bob Clark
Claims searched: All   **Date of search:** 23 June 2000

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G1A (AEAX, AEW, ARM)

Int Cl (Ed.7): G01D 5/24, 5/347, 5/36

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	WO 96/27118 A1	(OPTO GENERIC) Pages 17 to 28	1-3
X	US 5177393	(WEBBER) Line 12 col.4 to line 22 col.5, and lines 20 to 26 col.7	1-3
X	US 4977316	(MALCOLM) Line 20 col.2 to line 2 col.3	1,2
X	US 4902885	(KOJIMA) Line 61 col.6 to line 23 col.5	1-4

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
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